NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3371

ANALYSIS OF ACCELERATIONS, GUST VELOCITIES, AND AIRSPEEDS FROM OPERATIONS OF A TWIN-ENGINE TRANSPORT AIRPLANE ON A TRANSCONTINENTAL ROUTE FROM 1950 TO 1952

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SUMMARY

VGH time-history data obtained from one type of twin-engine transport airplane during operations from 1950 to 1952 on a transcontinental route are analyzed in order to determine the magnitude and frequency of occurrence of gust accelerations, gust velocities, and the associated airspeeds and altitudes. The present results compare favorably with results previously obtained for a similar type of twin-engine airplane during other operations. A somewhat less severe acceleration history for the present operations than that shown for the other airplane appears to have resulted from a lower operating airspeed in rough air for the present operations. The VGH data and a limited sample of V-G data from another route were synthesized to obtain estimates of overall gust and acceleration histories.

INTRODUCTION

For a number of years, studies of the gusts and gust loads experienced by transport airplanes have been made by the National Advisory Committee for Aeronautics through use of airspeed, altitude, and acceleration measurements taken during routine airline operations. This information in the past has proven useful in the formulation of design requirements, in studies of fatigue problems, and in the prediction of gust and load histories for new types of operations.

The present report represents a continuation of this work and presents an analysis of gust data obtained by means of an NACA VGH recorder installed in a twin-engine transport airplane. These data are analyzed herein to determine the magnitude and frequency of occurrence of gust accelerations, gust velocities, and the associated airspeeds for the period covered by the records. The results are compared with results obtained in reference 1 for a similar type of twin-engine airplane operated on another route. In order to obtain estimates of the overall gust and acceleration histories for the type of airplane considered, V-G data taken during another operation of the same type of airplane are used in conjunction with the present VGH data.

APPARATUS AND SCOPE OF DATA

The data presented herein were obtained with an NACA VGH recorder, which is described in detail in reference 2. The instrument yields a time-history record of the indicated airspeed, altitude, and normal acceleration for each flight of the airplane.

The pertinent characteristics of the airplane from which the data were obtained are described in the following table:

Design gross weight, W, lb	40,500
Wing area, S, sq ft	817
Aspect ratio, A	10.3
Mean geometric chord, $\bar{c}$, ft	9.72
Slope of lift curve per radian (computed), m	5.02
Design cruising speed (indicated), V_C, mph	280
Design speed for maximum gust intensity (indicated), V_B, mph	175
Never-exceed speed (indicated), V_{NE}, mph	315
Limit-gust-load factor (computed according to method of ref. 3)	2.76

These values were obtained from the manufacturer's design data and the airplane operating manual unless otherwise indicated. The slope of the lift curve was calculated (as recommended in ref. 4) from the relation $\frac{6A}{A + 2}$, where A is the aspect ratio. This calculated lift-curve slope is lower than the value used by the manufacturer in designing the airplane, and, accordingly, the calculated limit-gust-load factor of 2.76 is smaller than the design value of 3.17.

The data sample consisted of 12 VGH records representing 676 flight hours of routine commercial transport operation from April 1950 to April 1952. On these flights the airplane was used for short-haul passenger operations on a transcontinental route between New York and Los Angeles. Flights varied from about 10 minutes to $3\frac{1}{2}$ hours in length and averaged about 45 minutes. Although the average pressure altitude was about 5,800 feet, maximum altitudes of 15,000 to 20,000 feet were reached.

EVALUATION OF RECORDS AND RESULTS

The VGH records were evaluated essentially in accordance with the methods used in reference 1 to obtain frequency distributions of accelerations, airspeeds, and altitudes.

For evaluating the acceleration data, the steady-flight position of the acceleration trace was used as a reference from which the gust accelerations were read. Only the maximum value was read for each deflection of the acceleration trace greater than a threshold of ±0.3g from the reference. The results are summarized in table I in terms of the number of accelerations within 0.1g intervals for the total flight time and for the portions of the record that the airplane was considered to be in the climb, en-route, or descent condition. The flight hours, flight miles, and number of accelerations per mile for each distribution are presented in table I.

Figure 1 presents the acceleration data for the total sample in terms of the average number of accelerations that exceeded given values of $a_n/a_{n_{LLF}}$, the ratio of the measured acceleration to the acceleration corresponding to the computed limit-gust-load-factor increment, per mile of flight. The ordinate values for this figure were obtained from table I by progressively summing the total frequency distribution (by starting with the frequency for the largest value of a_n) and then dividing each sum by the total flight distance. The ratio scale is used to facilitate comparisons with data from other airplanes having different load factors. The solid line in the figure was faired through the data points to represent the present operation. For comparison, the dashed line in figure 1 represents the distribution of accelerations given in table III of reference 1 for another type of twin-engine airplane operated on a northern transcontinental route. A computed value of $a_{n_{LLF}}$ equal to 1.7g was used in plotting the data taken from reference 1.

In order to determine the gust velocities encountered during the present operations, the airspeed and altitude corresponding to each gust acceleration in table I were also read from the records. These values were then used to calculate the derived gust velocities by means of the gust-load formula discussed in reference 5. In these calculations, an average operating weight of 0.85 of the design weight and a mass parameter corresponding to the midpoint for each 5,000-foot-altitude interval were used. The results are summarized in table II for the total sample and for the given altitude intervals together with the flight hours, flight miles, and number of gusts per mile for each altitude. As a result of the use of the revised gust-load formula, the derived gust velocities for the present data are higher by a factor of roughly 1.6 than the corresponding effective gust velocities computed in most past analyses of airline gust data. (See, for example, ref. 1.)

The gust velocity distribution for the total sample in table II is plotted in figure 2 to represent the average number of gusts that exceeded given values per mile of flight. The low gust frequency indicated in figure 2 in the range of 7 to 10 feet per second resulted from incomplete frequency counts near the threshold value. The solid-line curve in the figure was faired through the data points to indicate the trend of the distribution. For comparison, the distribution of derived gust velocities for the operations reported in reference 1 is indicated in figure 2 by the dashed-line curve. Since the gust data of reference 1 are given in terms of effective gust velocity U_e, these data were converted for comparison to values of derived gust velocity U_{de}. Neither the present data nor those given in reference 1 have been corrected for dynamic-response effects.

Distributions of indicated airspeed for the climb, en-route, and descent conditions were obtained simply by reading the airspeed trace at 1-minute intervals for each flight. These distributions are given in figure 3 as the portion of the time spent at given airspeeds for each flight condition. In order to compare these data with the airspeeds used in rough air, the distributions of airspeeds at which gust accelerations greater than ±0.3g were experienced are shown in the figure by dashed-line curves. Also shown in the figure are the design speed for maximum gust intensity V_B, the design cruising speed V_C, and the never-exceed speed V_{NE}.

PRECISION AND RELIABILITY

The accuracy of the data presented herein is affected by the inherent instrument errors, installation errors, and reading errors. The inherent instrument errors and a general discussion of installation errors are given in reference 2. A discussion of reading errors applicable to the present data is contained in reference 1. The VGH installation met the basic installation requirements given in reference 2, and, consequently, the installation errors for the present data are felt to be negligible. The estimated total error for each of the quantities measured is

Acceleration, g units	±0.05
Airspeed, mph	±5
Altitude, ft	±300

In addition to the problem of instrument precision, a problem exists regarding the statistical reliability of the data samples (that is, applicability to extended periods of operation). Unfortunately, precise methods of determining the statistical reliability of the present results are not available. An indication of the reliability of the results may be obtained, however, by examining the variations among the data from individual records and groups of records forming the total sample. Based on considerations of the sample size (676 hours) and past experience with results of the type presented, the distributions of accelerations (fig. 1) and gust velocity (fig. 2) are estimated to be reliable within a factor of about 3 (on the ordinate scale) at the smaller acceleration and gust-velocity values and within a factor of about 4 at the higher values.

DISCUSSION

Accelerations

Comparison of the two curves in figure 1 indicates that the accelerations experienced for the present operations were somewhat less severe than those reported in reference 1 for operations of another type of twin-engine transport airplane on a northern transcontinental route. For a given frequency of occurrence, the fraction of the computed limit-gust-load factor exceeded for the present operation is about 0.85 of that for the operations covered in reference 1. In terms of frequency of occurrence per mile of flight, a given fraction of the computed limit-gust-load factor is experienced only about one-fourth as frequently in the present operations. An evaluation of the records for the two operations indicated that the average airspeed in rough air for the present data was $0.66V_C$ as compared with $0.76V_C$ for the reference data. This difference between the airspeed operating practices appears to be primarily responsible for the differences noted between the accelerations since the gusts encountered in the two operations (as are discussed later) are very similar.

An examination of the present acceleration data for the different operating conditions (see table I) indicates that the number of accelerations experienced during the en-route and descent conditions were approximately equal and also that the total number for en route and descent amounted to roughly 85 percent of the total number for the three conditions shown. When compared in terms of the average frequency of occurrence per mile, however, the frequencies of occurrence for the climb and for the descent conditions are seen to be roughly two and three times greater, respectively, than the frequency for the en-route condition. The greater frequencies of acceleration per mile during the climb and the descent conditions are primarily due to the greater amount of turbulence associated with the lower altitudes traversed during climb and descent.

Gust Velocities

Figure 2 indicates that the frequency of occurrence of gust velocities for the present operations was approximately the same as that for the twin-engine airplane operated on a northern transcontinental route (ref. 1). The generally good agreement between the results shown in the figure ordinarily would have been expected since the two operations are nearly alike in regard to airplane type, length of flight, average altitude, and general area of operations.

An inspection of the distributions of gust velocity for the different altitude intervals of table II indicates that a considerably smaller number of gusts per mile were encountered at altitudes above 5,000 feet than at altitudes below 5,000 feet. This decrease in frequency of occurrence of gusts is in agreement with the results obtained from previous work and, in general, has accounted for the small number of accelerations per mile of flight experienced during the en-route condition.

Airspeeds

The overall distributions of airspeed in figure 3 show, as might be expected, large variations in the airspeeds for the flight conditions indicated. It may be noted that the climb speeds were much lower than the en-route and descent speeds and that the highest speeds occurred during the descent. Inasmuch as the average airspeeds were $0.61V_C$, $0.74V_C$, and $0.71V_C$ for the climb, en-route, and descent conditions, respectively, the data indicate that the airplane generally was operated well below the design cruising speed V_C of 280 mph. The very low speeds noted during the descent (in the range roughly from 100 to 140 mph) are probably associated with maneuvering during approach and landing, which under the present classification was included in the descent condition.

Comparison in figure 3 of the distributions of airspeeds in rough air (dashed lines) with the overall airspeed distributions shows that only slight differences existed between the overall speeds and the speeds in rough air. For the climb condition, the speed in rough air appears to be slightly higher than the overall speeds and is close to the design speed in severe turbulence V_B of 175 mph for the airplane being considered. For en route and descent, the distributions indicate that slightly lower speeds were used in rough air than for overall operations. In general, however, these differences between the overall and rough-air speeds for the present operations are small and do not indicate any appreciable change in airspeed upon encountering rough air.

Overall Load and Gust Histories

As has been noted in previous reports (for example, ref. 1), VGH-data samples generally are limited in size and do not provide adequate information on the larger loads and gust velocities which occur very infrequently. In order to obtain estimates of the larger values for extended operations, therefore, recourse has been made in the past to synthesis of results from VGH and V-G data. Unfortunately, V-G data were not obtained from the same airline which supplied the present VGH data. A limited sample of V-G data covering 3,448 hours, however, was obtained during operations of the same type of airplane on a route in the southwestern portion of the United States. These records have been evaluated by routine procedures (ref. 6) for the accelerations and gust velocities, and the data are summarized in table III.

Estimates of the overall acceleration and gust histories for the present type of airplane are given in figures 4 and 5, respectively, and are based on the available VGH and V-G data. In both figures, a line has been faired to represent the general trend of the combined data samples. The acceleration and gust velocities from the V-G data appear to be larger and more frequent than would be expected by a simple extrapolation of the VGH data - a result which has been noted in previous investigations. In regard to this result, transport airplanes may be subjected at times to large maneuver accelerations and, although attempts are made during the evaluation of V-G records to eliminate obvious maneuver accelerations which occurred at the lower airspeeds during descent and landing, some influence from maneuvers might unknowingly be present in the V-G results shown.

Figure 4 indicates that the frequency of exceeding the acceleration $a_{n_{LLF}}$ corresponding to the limit-gust-load factor is about 3×10^{-6} times per mile, or one value larger than $a_{n_{LLF}}$ every 3×10^5 flight miles. Similarly, figure 5 indicates that the larger gust velocities, that is, $U_{de} = 50$ fps, are exceeded once in about 0.8×10^5 flight miles. These values for the miles to exceed $a_{n_{LLF}}$ and $U_{de} = 50$ fps are in general agreement with the results given in reference 6 for seven operations involving both two-engine and four-engine civil transport airplanes.

CONCLUDING REMARKS

An analysis of VGH data representing 676 flight hours of scheduled airline operations from 1950 to 1952 of a twin-engine transport airplane indicates that the gusts encountered are in good agreement with those previously reported for another type of twin-engine transport airplane. A somewhat less severe acceleration history for the present operations than that shown for the other airplane appears to have resulted from a lower operating airspeed in rough air for the present operations.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 23, 1954.

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4. Donely, Philip: Summary of Information Relating to Gust Loads on Airplanes. NACA Rep. 997, 1950. (Supersedes NACA TN 1976.)

5. Pratt, Kermit G.: A Revised Formula for the Calculation of Gust Loads. NACA TN 2964, 1953.

6. Walker, Walter G.: Gust Loads and Operating Airspeeds of One Type of Four-Engine Transport Airplane on Three Routes From 1949 to 1953. NACA TN 3051, 1953.

TABLE I.- FREQUENCY DISTRIBUTIONS OF ACCELERATIONS BY FLIGHT CONDITION

a_n, g units	Frequency distribution			Total
	Climb	En route	Descent	
0.3 to 0.4	635	1,722	1,886	4,243
.4 to .5	135	437	413	985
.5 to .6	35	117	108	260
.6 to .7	9	35	29	73
.7 to .8	2	5	9	16
.8 to .9	2	3	6	11
.9 to 1.0	1	1	1	3
1.0 to 1.1	---	0	0	0
1.1 to 1.2	---	1	1	2
Total	819	2,321	2,453	5,593
Flight hours	101	414	161	676
Flight miles	1.72×10^4	8.62×10^4	3.19×10^4	1.35×10^5
Number of accelerations per mile	4.7×10^{-2}	2.7×10^{-2}	7.7×10^{-2}	4.1×10^{-2}

TABLE II.- FREQUENCY DISTRIBUTIONS OF DERIVED GUST VELOCITY BY ALTITUDE

U_{de}, fps	Frequency distribution for -			
	0 to 5,000 ft	5,000 to 10,000 ft	10,000 to 20,000 ft	Total
8 to 12	1,503	419	30	1,952
12 to 16	1,932	683	90	2,705
16 to 20	480	133	50	663
20 to 24	146	27	28	20[illegible]
24 to 28	29	8	1	3[illegible]
28 to 32	20	---	5	25
32 to 36	4	---	3	7
36 to 40	1	---	---	1
40 to 44	0	---	---	0
44 to 48	0	---	---	0
48 to 52	1	---	---	1
Total	4,116	1,270	207	5,593
Flight hours	299	294	83	676
Flight miles	5.98×10^4	5.88×10^4	1.66×10^4	1.35×10^5
Number of gusts per mile	6.9×10^{-2}	2.2×10^{-2}	1.3×10^{-2}	4.1×10^{-2}

TABLE III.- FREQUENCY DISTRIBUTIONS OF MAXIMUM ACCELERATIONS AND MAXIMUM GUST VELOCITIES FROM V-G DATA

Maximum normal acceleration, $a_{n_{max}}$, g units	Frequency
0.5 to 0.6	1
.6 to .7	0
.7 to .8	1
.8 to .9	5
.9 to 1.0	3
1.0 to 1.1	3
1.1 to 1.2	3
1.2 to 1.3	4
1.3 to 1.4	2
1.4 to 1.5	4
1.5 to 1.6	0
1.6 to 1.7	1
1.7 to 1.8	1
1.8 to 1.9	0
1.9 to 2.0	2
Total	30
Flight hours	3,448
Flight miles	6.9×10^5

Maximum derived gust velocity, $U_{de_{max}}$, fps	Frequency
20 to 24	1
24 to 28	1
28 to 32	3
32 to 36	6
36 to 40	4
40 to 44	3
44 to 48	6
48 to 52	1
52 to 56	1
56 to 60	1
60 to 64	1
64 to 68	1
68 to 72	1
Total	30
Flight hours	3,448
Flight miles	6.9×10^5

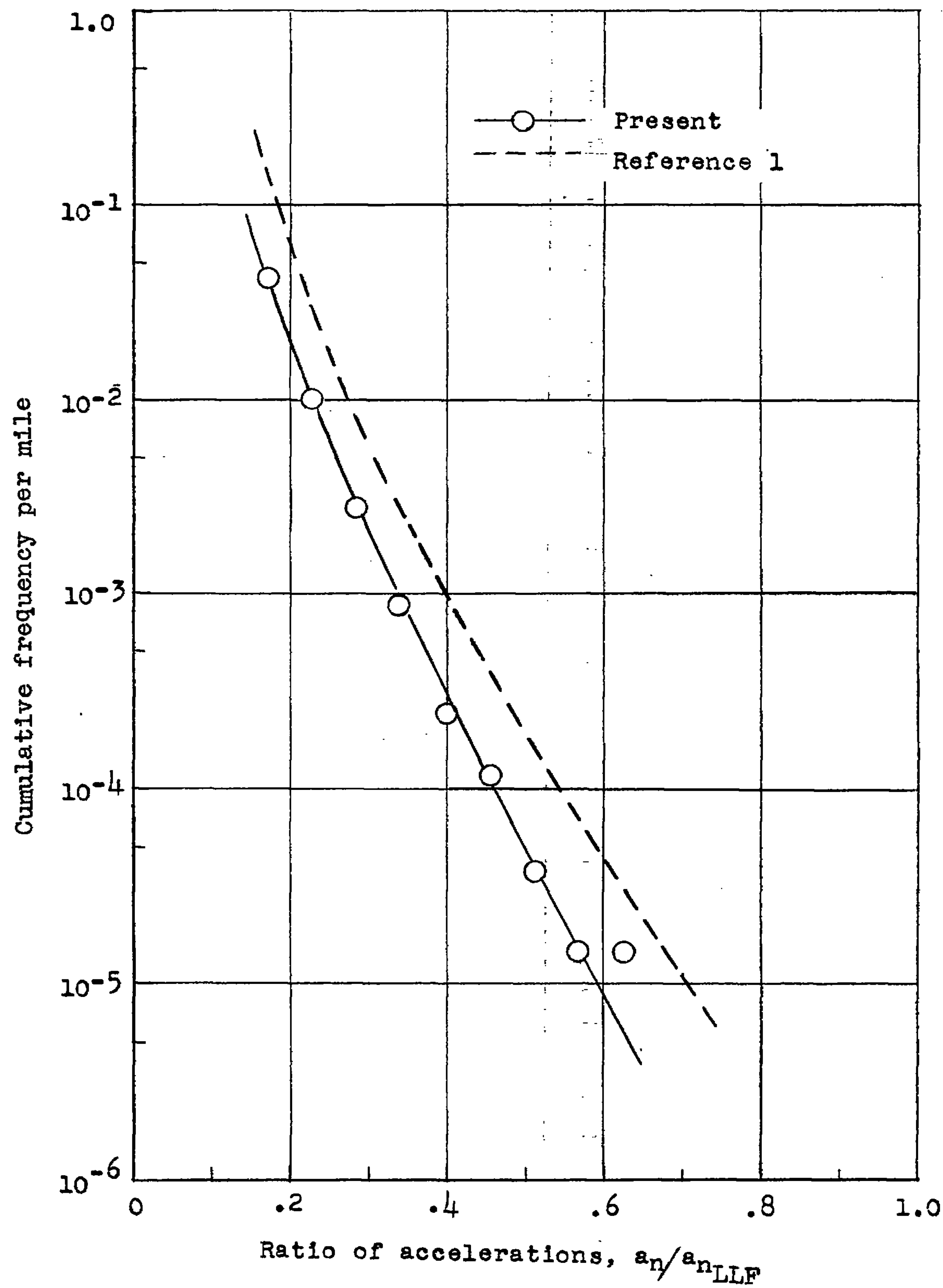

Figure 1.- Comparison of load histories for two operations.

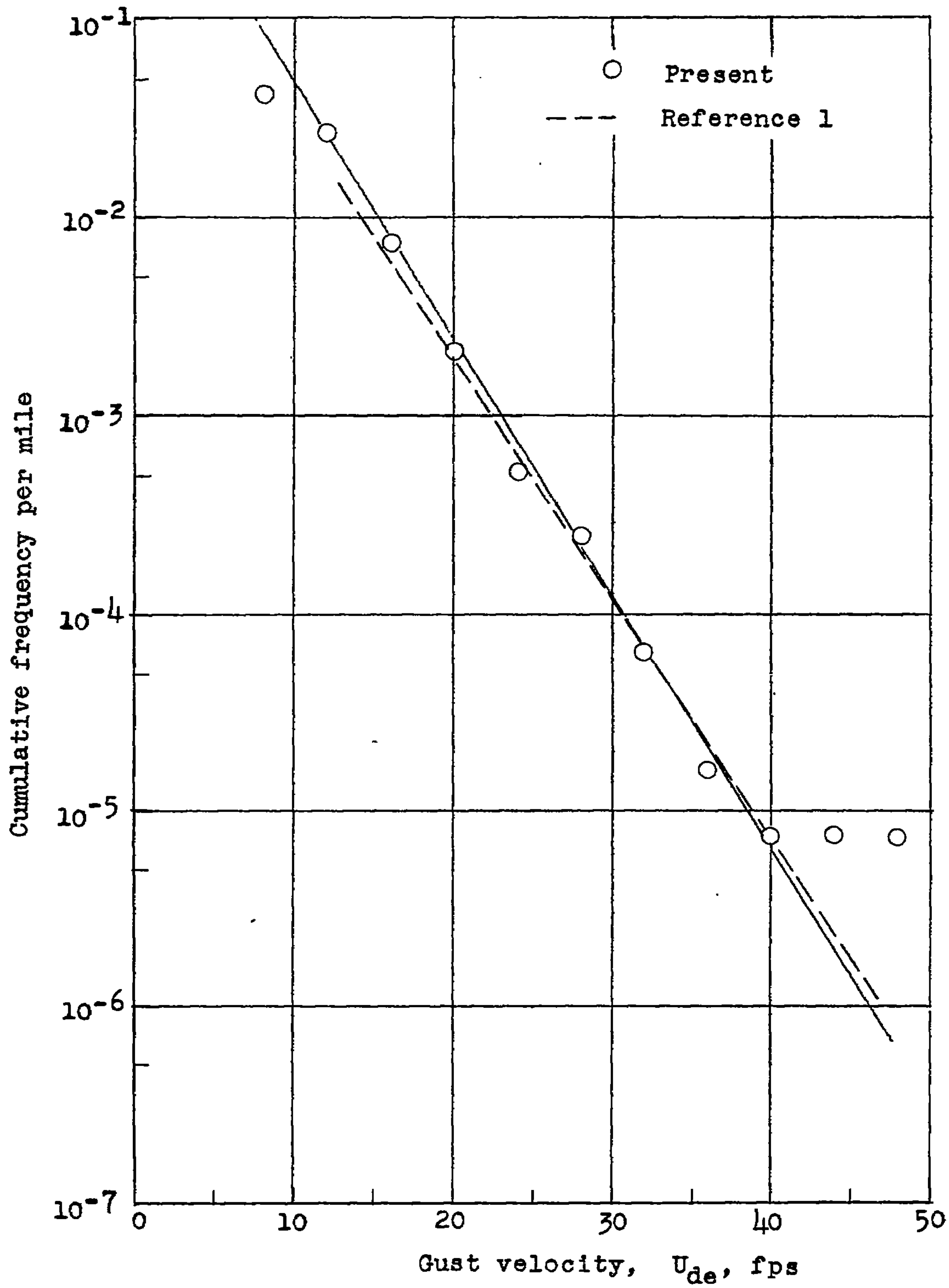

Figure 2.- Average frequency of exceeding given values of gust velocity per mile of flight.

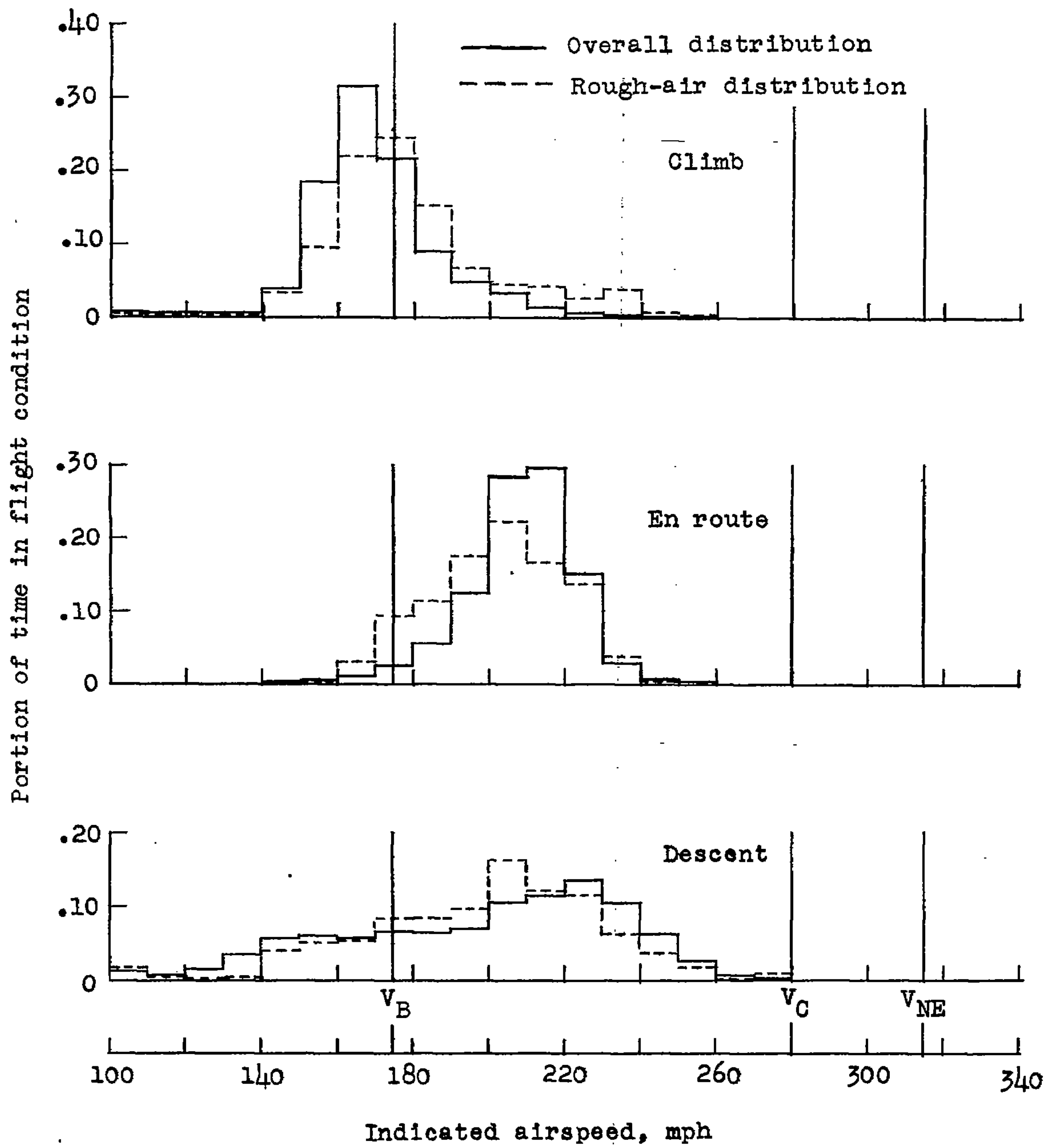

Figure 3.- Comparison of distribution of overall airspeed with distribution of airspeed in rough air by flight condition.

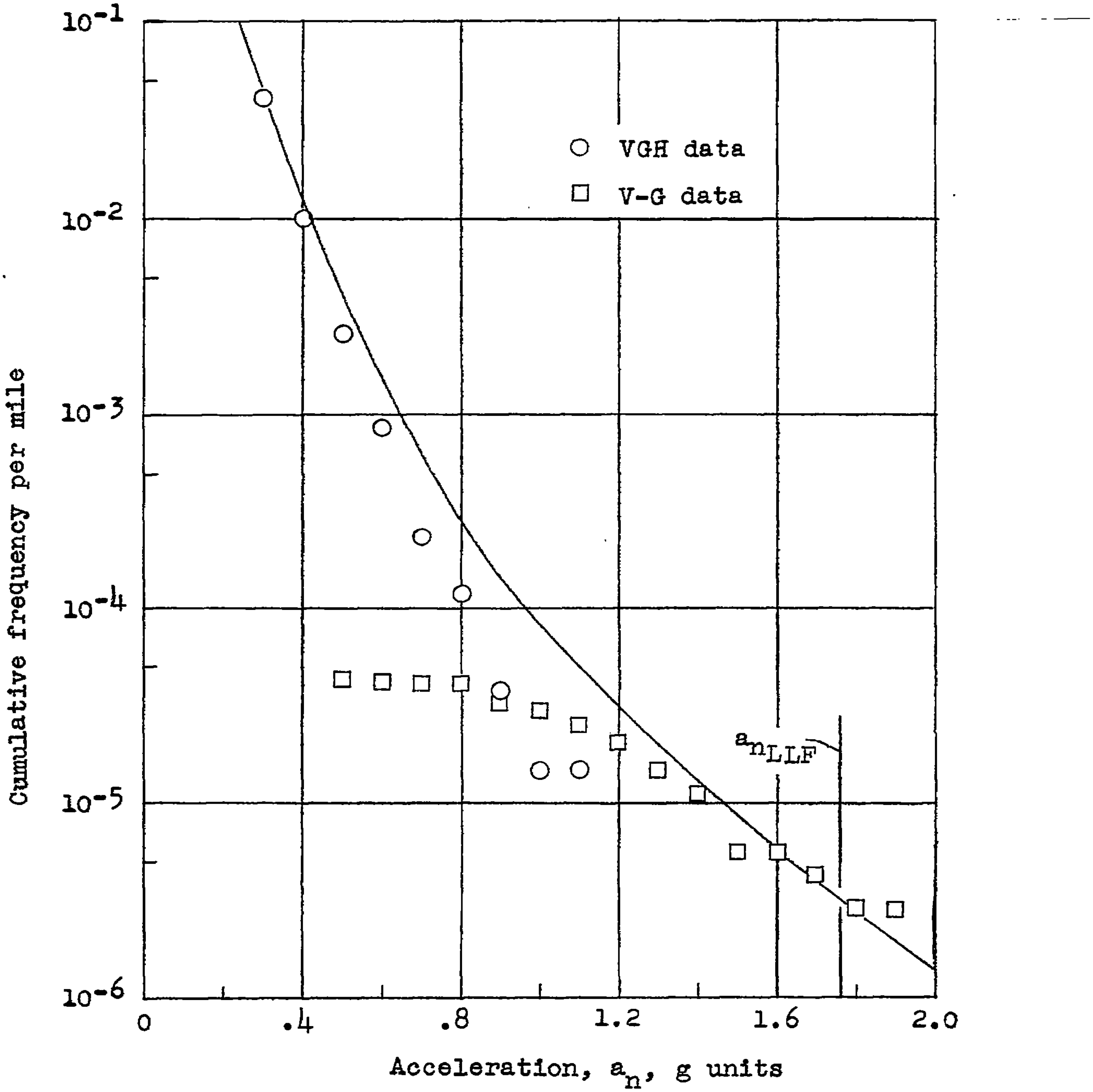

Figure 4.- Composite curve of average frequency of exceeding given values of acceleration per mile of flight.

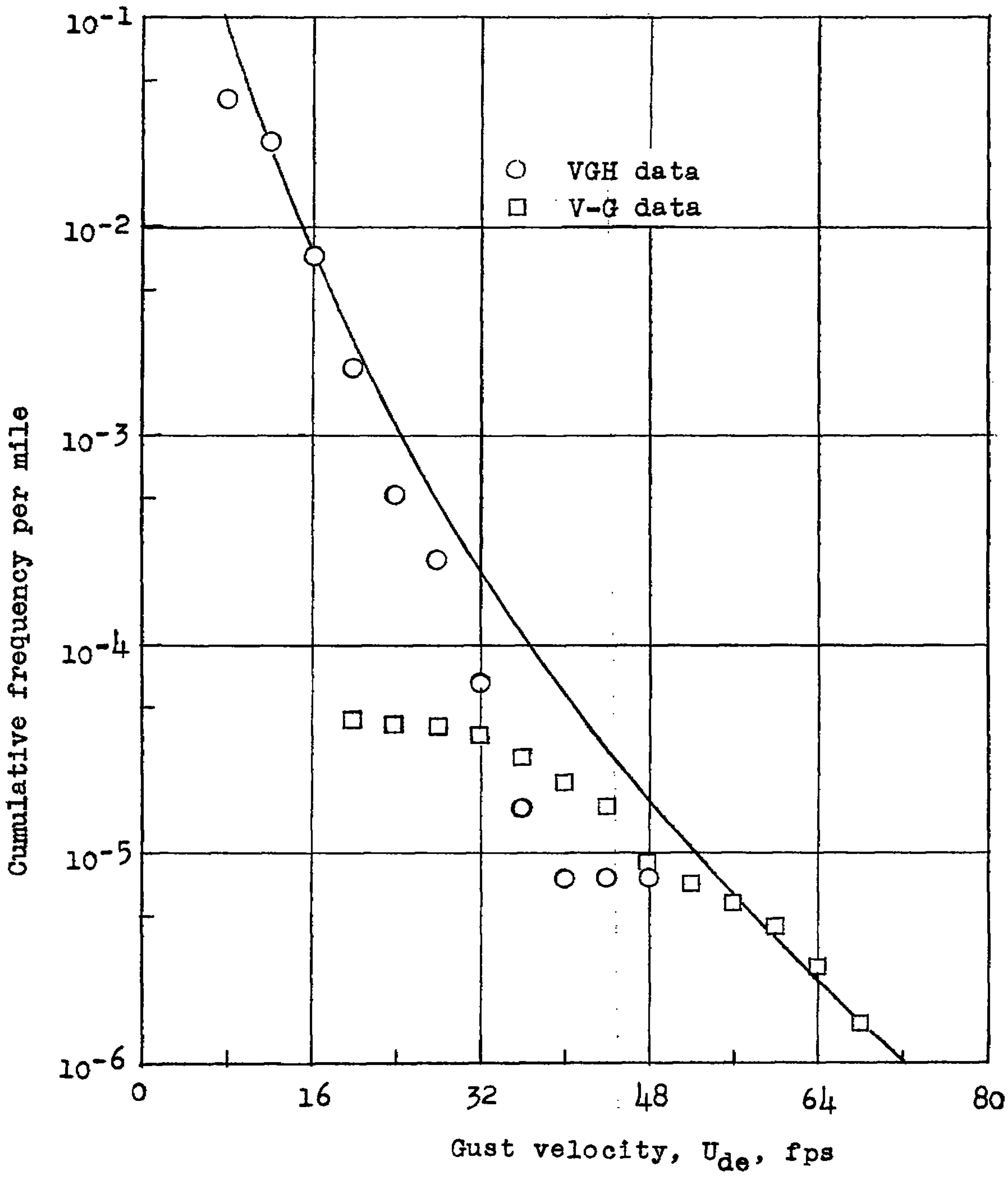

Figure 5.- Composite curve of average frequency of exceeding given values of gust velocity per mile of flight.